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"The Effects of Cloud Inhomogeneities Upon Radiative Fluxes, and the Supply of a Cloud Truth Validation Dataset"

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Submitted by

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to

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1. Work Accomplished During the Report Period

This work is directed towards the development of algorithms for the ASTER science/instrument teams. Special emphasis is being placed on a wide variety of cloud optical property retrievals, and especially retrievals of cloud and surface properties in the polar regions.

2. Research Activities

2.1 Cloud algorithms

2.1.1 ASTER Polar Cloud Mask

During this reporting period we tested an adaptive thresholding technique in the first stage (i.e., cluster based classifier) of the ASTER Polar Cloud Mask algorithm. It has significantly improved the accuracy of the classifier with respect to separation of ice and cloud over ice, and land and cloud over land. The adaptive thresholding is performed in the arctan of Band 4 and Band 5 feature space for the classification of various states of frozen water such as snow, ice, wet ice, thin ice, slush, etc. and cloud over those surfaces. It is performed in the Band 2 and Band 4 feature space for the classification of land and cloud over land. After testing this technique on our 82 Landsat TM scenes, the average classification fraction has increased to approximately 85 percent for this stage. Our previous tests of the first stage resulted in an average classification fraction of 60 percent. A simple nearest neighbor algorithm based on Euclidean distance also has been appended to the first

stage which classifies unclassified pixels based on the proximity of their feature vectors to those of the classified pixels. An increase in classified pixels of up to 10 percent has been observed in some scenes. The nearest neighbor algorithm is very conservative in that an unclassified pixel is only classified if its feature vector is unambiguously close to the mean feature vector of a particular class.

We are also testing a variation of the rule based classifier (i.e., the second stage) on our Landsat TM imagery. We are calling this variation of the classifier the Paired Histogram Method (PHM). The PHM is different from the original rule based method in that feature histograms derived from the sample data are used in the voting or balloting scheme instead of simple thresholds. The histograms for each combination of 2 classes for each feature are compared. The PHM is being tested in several ways. For example, in the simplest case, a step function is generated for each class in each pairwise comparison based on the range of feature values for each class. In the feature space where the histograms overlap (if there is any), the step function for each class is set to 1. In the space in which the histogram for one class is higher than that of the other histogram, the function for the higher one is set to 1 and that for the lower one is set to 0. If the histogram values are 0 for both classes then both functions are set to 0. In the balloting process, in each pairwise comparison either one of the classes get a ballot of 1 and the other a zero or they both get a 0 or 1. In another implementation of the PHM, the actual feature histogram values are used and the ballot for each class in each comparison can range anywhere from 0 to 1. Normalization of the histogram is either based on the peak value in the histogram or on the total area under the histogram. The feature histograms used in each class comparison are selected in a preprocessing step and the number of features used is variable from 1 to 10. Currently, the best results have been obtained when using the 3 best features. The best features are those that have the most separability and are determined from the measures of divergence, histogram overlap, and gap between the distributions. Another enhancement that was implemented and is being tested in the PHM is an improvement to the feature selection process based on the cross correlation metric. Frequently, the best features for separating a pair of classes are highly correlated. If three features are being used in a test to determine the best choice between two classes, then ideally the three features will be totally independent; that is, each feature is uncorrelated with the other two features. Of course, in practice there are seldom three features that are totally independent; therefore, a threshold is applied to the cross correlation metric between each pair of features. For example, if three features are selected (based on their ability to separate a given pair of classes), then the cross correlation for each of the three combinations of features is computed. If any one of the cross correlations is less than 0.8, then only one of the two features is retained and another feature is selected from the ranked list of best features for the pair of classes under consideration. The addition of this cross correlation test has increased the performance of the classifier in tests on samples by nearly 10 percent to approximately 95 percent over all classes. It has improved the performance of the classifier in scene classification but it is difficult to quantify the improvement as a percentage. The classifier has been applied to all 82 Landsat TM scenes. The classification accuracy of the technique is estimated to be between 80 and 90 percent; however, when the output of this classifier is combined with the output of first stage (discussed above), the accuracy approaches 90 percent. With the

current accuracy it is now possible to examine the problematic scenes in more detail and some additional improvement in accuracy should be possible. During the next few months, we will be working towards integrating this classifier and the first stage into one process. We are also planning to incorporate the adaptive thresholds of the previous paragraph into the PHM. The samples will be parsed into subsets based on the thresholds derived from the scenes from which they were extracted. The PHM then will be trained on each subset of samples. The appropriately trained PHM will be applied to a scene based on the adaptive threshold for the scene being classified. We are currently writing a paper detailing the implementation of this algorithm (by itself) on the Landsat TM data and the results of the classification.

The fuzzy logic classifier was also tested on a number of scenes with reasonably good results. The number of features used was pruned down to 11 based on some forward and backward discriminant analysis. In this version of the classifier the membership functions are Gaussian in which the mean and variance are derived from the sample data. We also incorporated the adaptive thresholds used in the first stage of the classifier (i.e., the cluster based classifier) into the fuzzy logic classifier. For example, the adaptive thresholds for the Band 2 and Band 4 feature space (i.e., for the classification of land) and the arctan of Band 4 and Band 5 feature space (i.e., for the classification of various states of frozen water such as snow, ice, wet ice, thin ice, slush, etc.) were used to define dynamic or adaptive membership functions. The other tests or rules in the cluster based classifier also were incorporated into membership functions. This version of the fuzzy logic classifier was tested on 10 scenes and a subjective estimate of the classification accuracy is between 80 and 90 percent. The advantage of applying the fuzzy logic classifier in this manner, as compared to the cluster based approach which uses thresholding, is that the membership functions can be designed to "fuzzify" or extend the decision boundaries to ambiguous feature vectors. The certainty measure then decreases as the feature vector becomes more ambiguous and it is possible then to assign confidence values to each feature vector. We plan to test this version of the fuzzy logic classifier on additional scenes and experiment with the slope at the edges of the membership functions in an attempt to determine critical certainty measures. It remains to be seen how well this classifier performs in relation to the others until more scenes have been tested.

We are continuing testing of a hierarchical neural network (HNN). We have generated a number of different feature sets to determine whether an increased number of features improves the performance of the classifier. Confusion matrices from the classifier when using 18 features indicated training set accuracies over 90 percent. When using 45 features the accuracies in the confusion matrices increased a few more percent. However, when applying the 2 networks to actual imagery there is no apparent improvement in the results. Subjectively speaking, the accuracy of the HNN when applied to full scenes is 80 to 90 percent. We are in the process of evaluating whether the network is superior to other techniques (i.e., the PHM classifier and the fuzzy logic classifier discussed above) in the classification of specific classes and if it might be useful in the second stage of the ASTER Polar Cloud Mask classifier. We are also planning to incorporate the adaptive thresholds described in the first paragraph into the HNN. The samples will be parsed into subsets based on the thresholds derived from the scenes from which

they were extracted. The HNN then will be trained on each subset of samples. The appropriately trained HNN will be applied to a scene based on the adaptive threshold for the scene being classified.

Currently, our only method for assessing the accuracy of the polar cloud masking algorithm, quantitatively, is through analysis of confusion matrices. The confusion matrices are derived from the results of applying the algorithm to the labeled samples and, therefore, do not provide a quantitative measure of the accuracy of the algorithm when applied to a specific scene. Up to now the scene classification accuracy has been estimated subjectively. The ideal method for determining this accuracy would be to have a manually classified mask for each and every scene against which the algorithm derived mask could be compared. Since it is not practical to do this, we are in the process of developing a methodology, using human analysts, that will provide an estimate of this accuracy. Through a random process, one of 82 scenes will be selected followed by a random selection of a small subregion within the scene. The size of the subregion will be selected such that a human analyst can visually determine the fraction of each class present. We expect the optimum size of the subregion (or box) to be on the order of 16 by 16 pixels. The analyst will be able to display any band or 3-band overlay of any 3 bands to augment his determination of the classes present in the subregion. Approximately 5 analysts will perform this random manual classification process approximately 100 times each. The statistics from these 500 manually classified subregions will then be used to estimate the classification accuracy of a classifier. The 500 classified subregions should provide for adequate sampling and the use of several analysts should provide for objectively derived results. The results from this process will be included in the paper describing the algorithm we are currently preparing for journal submission. In addition, this methodology will be applied to several different individual classifiers (i.e., hierarchical neural network, paired histogram, and fuzzy logic) to determine if some classifiers are superior to others in identifying specific classes.

We have been collaborating with Dorothy Hall and George Riggs of NASA Goddard in a comparison of the results from their SNOMAP and ICEMAP classifiers with our classifier. We are exchanging Landsat TM data and have tested the classifiers on some of the same scenes. We received 14 additional scenes over the last few months and expect to receive an additional 10 in the near future. We are currently loading those scenes into our system and will be applying our classification algorithms to those scenes. We will also be collaborating Anne Nolin of the University of Colorado at Boulder in the application of her adaptive filtering techniques to the classification of snow and ice in LANDSAT TM polar data. We are currently loading all our LANDSAT TM polar data onto 8 mm tape to be sent to her for testing. We have sent 24 scenes to date and hope to send the balance by the end of next month.

Ron Welch travelled to NASA Goddard in early September for a workshop to present classification results from the cloud mask algorithm and discuss some of the initial comparisons with the SNOMAP and ICEMAP algorithms. He also attended the ASTER Science Team Meeting held in Japan this past November.

During this reporting period Rich Irish of the Landsat Project Office at GSFC began transferring his 500 plus data set of subsampled Landsat TM data. The current Landsat TM cloud masking algorithm misclassifies warm clouds and there is interest in testing some of our methodologies on this problem. The current version of the polar cloud mask algorithm is too slow to be applied to the volume of data required by the Landsat TM cloud masking operation; however, we hope to find some subprocess in the algorithm that can be applied successfully.

2.1.2 Simulation of 3-D Cloud Effects

We continue to work on a study that will show the impact of various factors on the retrieval of cloud properties based on Landsat TM and AVIRIS data. We have selected a set of approximately 15 scenes in which there is broken cloudiness over both land and water. For land scenes, we are investigating the uncertainty in the retrieved properties as a function of the range of background albedos found in the scene. Initial results indicate that if we vary the background albedo from the mean value (for the clear background areas) minus 1 standard deviation to the mean value plus 1 standard deviation (on the order of 0.1 to 0.15 for the scenes we are examining), the retrieved mean effective radius changes very little but the retrieved mean optical depth can change by as much as 5. We will also be looking at the impact on retrievals due to the local aspect of cloud faces and cloud shadowing. We also plan to look at the impact of spatial degradation on the retrievals. We are currently converting our Monte Carlo routine from IDL to C. We hope that the C version will be much faster and enable us to run much larger numbers of photon trajectories. The intent is to increase the number of photon trajectories sufficiently to generate radiance patterns that can be compared to those obtained from our analytical Picard Iterative Method for 3-D radiative transfer.

2.1.3 Cloud Base Height Retrievals

A paper entitled "Estimation of Cirrus Cloud Height Using Landsat Imagery" by Yasushi Inomata and Ronald M. Welch, that was submitted earlier this year to *JAM*, was returned earlier this summer for modification and editing. The paper describes a technique for estimating the height of clouds with thin and/or ill defined edges using 2-D cross correlation. We augmented the paper with some additional Landsat TM imagery and compared the results with temperature based retrievals. The comparisons indicate reasonably good agreement (within 10 percent). The paper was resubmitted and was accepted. The page proofs were received and returned and we expect it to appear in print early in 1996. During this last semester a student adapted the technique to the UNIX environment and added some graphical user interfaces to facilitate analysis. During the next semester we plan to have this work extended to the retrieval of cloud thickness and cloud morphology incorporating a 3-D temperature-based wireframe cloud analysis developed in Kuo *et al.*, 1992.

2.1.4 Retrieval of Aerosol Optical Depth from AVIRIS

We received notification this reporting period that our paper entitled "Retrieval of aerosol spectral optical depth from AVIRIS" was accepted for publication in the *International Journal of Remote Sensing*. We expect it in print sometime next spring.

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13. ABSTRACT (Maximum 200 words)

The ASTER polar cloud mask algorithm is currently under development. Several classification techniques have been developed and implemented. The merits and accuracy of each are being examined. The classification techniques under investigation include fuzzy logic, hierarchical neural network, and a rule-based scheme based on sample histograms called the Paired Histogram Method. Scene adaptive methods also are being investigated as a means to improve classifier performance. The feature, arctan of Band 4 and Band 5, and the Band 2 vs. Band 4 feature space are key to separating frozen water (i.e., snow, ice, slush, wet ice, etc.) from cloud over frozen water, and land from cloud over land, respectively. A total of 82 Landsat TM circumpolar scenes are being used as a basis for algorithm development and testing. Numerous spectral features are being tested and include the 7 basic Landsat TM bands, in addition to ratios, differences, arctans, and normalized differences of each combination of bands.

A technique for deriving cloud base and top height is developed. It uses 2-D cross correlation between a cloud edge and its corresponding shadow to determine the displacement of the cloud from its shadow. The height is then determined from this displacement, the solar zenith angle, and the sensor viewing angle.

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